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THD and Compensation Time Analysis of Three-Phase Shunt Active Power Filter Using Adaptive Spider Net Search Algorithm (ASNS)

Saifullah Khalid

Manager(ATC), Airports Authority of India, INDIA

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Abstract: In this paper, a novel Adaptive Spider Net Search Algorithm **(**ASNS) has been presented, which has been used for the optimization of conventional control scheme used in shunt active power filter. The effectiveness of the proposed algorithm has been proved by applying this in balanced, unbalanced and distorted supply conditions. The conventional sinusoidal current control technique has been used. The soft computing algorithms have been used to give the optimum results. The superiority of ASNS algorithm over existing Genetic Algorithm results has been presented by analyzing the THD and compensation time of both the algorithms. The simulation results using MATLAB model ratify that algorithm has optimized the control technique, which unmistakably prove the usefulness of the proposed algorithm in balanced, unbalanced and distorted supply system.

Keywords: Active power filter (APF), Adaptive Spider Net Search Algorithm, Genetic Algorithm, Harmonic Compensation, IEEE 519-1992.

1. INTRODUCTION

Non-linear loads cause the harmonics into the facility arrangement and these harmonics produce copiously of issues within the system. Once application of unbalanced and nonlinear loads will increase, supply gets distorted and unbalanced. These currents foul the provision point of the utility. Therefore, it is important to compensate unbalance, the harmonic and reactive component of the load currents. Whereas once supply is unbalanced and distorted, these problems worsen the system [1]-[3]. By the appliance of shunt active power filters within the system can eliminate harmonic, reactive and unbalanced current still as improve the ability provide performance and so the steadiness of system.

Today, the soft computing techniques are used wide for optimization of the system applied or in control system; algorithms [4]-[8] used for locating the optimized values of the controllers variables [4]-[12], optimization of active power filter using GA [9]-[12], power loss diminution using particle swarm optimization [13], neural network ANN Control [14]-[18] applied in each machinery and filter devices.

In this paper, two different soft computing techniques i.e. ASNS & GA have been applied for reduction of harmonics and others downside generated into the balanced, unbalanced and distorted system attributable to the nonlinear loads [1].
The results obtained with each the algorithms are far better than those of typical strategies. ASNS algorithm has given the better results as compared to GA and traditional scheme. The effectiveness of the planned scheme has been evidenced by the simulation results mentioned. The result justified their effectiveness.

In this paper, ASNS algorithm has been wont to search the optimum value of PI controller parameters. For the case of GA, an optimum value of filter inductor has been calculated. The controlling theme has been modeled on the idea of Sinusoidal current control Strategy.

The paper has been organized in the following manner. The Active Power Filter configuration and also the load into consideration are mentioned in Section II. The control algorithm for Active Power Filter is mentioned in Section III. MATLAB/ Simulink based mostly simulation results are mentioned in Section IV and at last Section V concludes the paper.

E-mail:saifullahkhalid@outlook.com, dr.s.khalid@ieee.org

2. SYSTEM DESCRIPTION

The supply system (Balanced/Unbalanced/Distorted) may be a three-phase system with the supply frequency of 50 Hertz of 110V. Shunt APF compensates the harmonic currents within the system and, therefore, improves the power quality. The shunt APF is completed by using one voltage supply inverters (VSIs) connected at the point of common coupling (PCC) with a common DC link voltage. The load into consideration may be a 3 sort of non-linear loads. 1st load used 6-pulse current source converter Bridge. Second is that the 3 phase diode bridge rectifier with inductance of 300mH and third one is 3 phase diode bridge rectifier with capacitance of 1000uF (Load 3). The DC capacitor is of 3000 µF and DC voltage reference used is 600 V. The filter inductor and capacitor is of 2.5 mH and 30 µF respectively.

3. CONTROL THEORY

The projected control of APF depends on Sinusoidal current control strategy optimized with soft computing techniques like adaptive Spider Net Search algorithm/ Genetic algorithm. Overall control theme using Sinusoidal current control strategy with the application of Adaptive Spider Net Search algorithm/Genetic algorithm has been dealt in following sections.

A. Design Using Novel Adaptive Spider Net Search Method (Proposed)

Adaptive Spider Net Search (ASNS) Algorithm is proposed for combinatorial optimization issues. Non-linear continuous optimization issues need a robust search methodology to resolve them and this new adaptive Spider Net Search (ASNS) Algorithm has been developed for them.

In the ASNS algorithm, an eternal search space has been discretized and back-tracking and adaptive radius features are utilized to lift the performance of the search method.

In this paper, the proposed ASNS Algorithm searches the optimum value of the proportional integral controller parameters i.e. K_p and K_i and therefore the objective function (OF) is determined such as to give their optimum value with the conditions of % overshoot, rise time and settling time. Objective function has an equation that has 3 variables i.e. % overshoot, rise time and settling time. Initially, the Boundary of Kp and Ki, their higher limits and lower limits, then radius value, conditions for ASNS backtracking, objective function and stop criteria has been outlined.

Net of spider has been supposed of the shape of the hexagon. We have used 500 hexagons and every corner of the hexagon, we have defined some random values of K_p & K_i which will be within the range of predefined initial values. Best value of each hexagon will be saved as first corner value of next hexagon. The comparison will move in clockwise as well as zigzag direction for the complete check of optimum value. After every comparison, best value will be compared with next value on the next corner and then the best outcome will be saved and will be compared to next one. This process will repeat itself and will stop when stopping criteria fulfills. We have considered 500 hexagons as shown in figure 1. We have observed that comparison of each hexagon corner values goes through nine times as shown in figure 2 and that is the reason for selecting maximum Searching iteration (4500 iterations) for ASNS as the stop criterion. There is a predefined list named as Spider net list, which contains the values which have been distributed over the corners of the hexagons.

Function evaluations: since this paper is based on the critical analysis based on THD of the source it has been seen that the objective function taken has shown its effectiveness, which can be seen from the reduction of THD. Computational time has conjointly been seen terribly less i.e. within seconds, all iterations are over and optimum values of K_p and K_i are often seen on MATLAB/Simulink complier. We will see that this method is extremely stable since it's been calculated offline and so are often used to replace the present values. Robustness of this algorithm is often understood by the great results and less computational time. Convergence analysis has been done offline. The range of iterations with variation in K_p and K_i values has been taken to prove the pliability of the algorithm. This algorithm is extremely convenient to use because of the programming and fewer computational time. The feasibleness and good thing about the algorithm are proved by the simulation results. It's in no time. The parameters i.e. K_p and K_i have been set at random at first and so it has been tuned by using this algorithm offline. Standard equations of K_p and K_i using settling time ($T_{Settling}$), rise time (T_{Rise}) and percent overshoot (P.O.) are used for locating the objective function within the program.

There has been a counter used, which will count the number of iterations and, therefore, the program will stop automatically once the count is up to 4500 i.e. stopping criteria is 4500 iterations. Figure 3 shows the flow chart for the search of parameters using Adaptive Spider Net Search (ASNS) Algorithm.

Objective function (O.F.) is defined by

$$O.F.(T_{Rise}, Ts_{ettling}, P.O.) = R(T_{Rise}) + S(T_{Settling}) + P(P.O.) \quad (1)$$

R+S+P=1 (2)

P.O. is the percent overshoot.

T_{Rise} is the rise time.

$T_{Settling}$ is the setting time.

R, S, and P are the priority coefficients of T_{Rise} ,$T_{Settling}$, P.O. respectively.

In this paper, the values of (R, P, and S are set to 0.33, 0.33, and 0.34, respectively. The ASNS search will try to find the best controller parameters to achieve the minimum O.F. value. The algorithm has been explained stepwise for more clarity.

Step 1: Spider Net list having values of K_p and K_i have been loaded and the counter has been made zero, which will check the number of iteration.

Step 2: the value of the objective function has been calculated for initial values of K_p and K_i.

Step 3: Resultant of step 2 has been compared with the calculated value of the objective function of Spider Net list i.e. first corner starts from the left side.

Step 4: If the results are not better, it will be saved in spider net list and then counter will automatically be increased and there will be change in K_p and K_i values from the spider net list and these value will replace the previous value and then objective function for these values will be calculated and then again go to step 3.

Step 5: If the results are better than Spider Net list solutions, it will be saved as the best solution.

Step 6: If number of iteration i.e. count value is 4500, the results with the optimum value of K_p and K_i will be shown otherwise it will check the counter value and change the K_p and K_i values from the spider net list and these value will replace the previous value and then objective function for these values will be calculated and then again go to step 3.

The values initially used for K_p and K_i were 0.1 and 50 respectively. After the calculation, ASNS algorithm gives the value 0.194 and 15.32. It has been observed that while using these ASNS calculated values of K_p and K_i, the THD of supply current and voltage are reduced staggeringly that proves that the values are optimum.

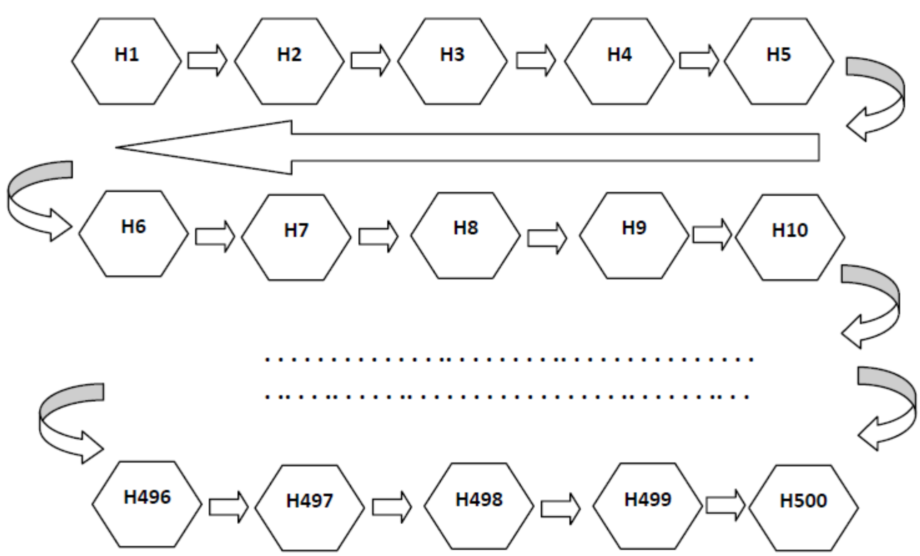

Figure 1. 500 Hexagons Used as Spider Net for Optimization

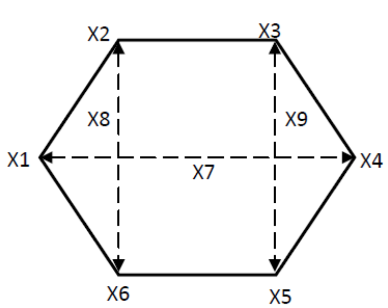

Figure 2. Values Distribution & Comparison over a Single Hexagon

B. *Design Using Genetic Algorithm*

GA could also be a search technique that's used from generation to generation for optimizing performs. In fact, GA works on the rule of survival of the fittest. For the selecting the parameters used in the controller using GA, the analysis methodology wants a check, performed on-line on the particular plant or off-line with simulations on the computer. Every on-line and offline methodology are having advantages and disadvantages each. If we've got a bent to means on-line approach, the foremost advantage is that the consistency of the final word answer, as a results of its chosen on the idea of its real performances, whereas if we have a tendency to predict concerning its disadvantage, it always involves thousands of tests to attain an even result i.e. this optimization methodology will take long run for experiments to run on the real system. Simply just in case of the off-line approach, GA improvement relies on a so much plenty of precise model of the system in conjunction with all elements, all nonlinearities, and limits of the controllers. It has to be compelled to, however, be well-known that a negotiation must be met in terms of simulation accuracy and optimization time. Offline, computer simulation using MATLAB Simulink has been applied to hunt out the optimum value.

In this paper, the GA is applied to figure out the appropriate APF parameters i.e. device filter (L_f). The boundary and limits of parameters inside the filter have been outlined and a program using genetic algorithm has been written to return up with the foremost effective value of the filter device.

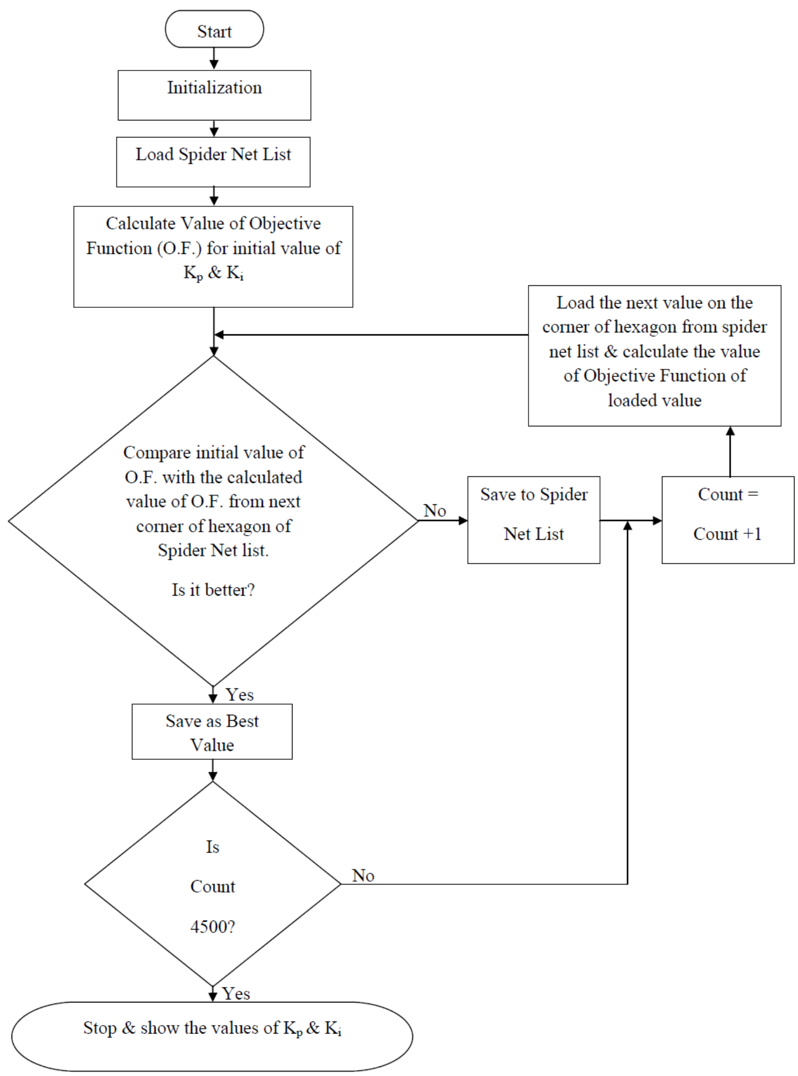

Figure 3. Flow Chart for Search of Parameters Using ASNS

C. Control Scheme

In this paper, sinusoidal current control strategy has been used for active power filter with the appliance of soft computing algorithms. The soft computing techniques like ASNS & GA are accustomed provide the most effective optimized values of the essential parts of the system so the system can provide the most effective performance below all conditions. The controller has been modeled using MATLAB/Simulink and it's been simulated below for balanced, unbalanced and distorted supply conditions.

4. SIMULATION RESULTS & DISCUSSIONS

In this section, 3 sorts of supply system i.e. balanced, unbalanced supply and distorted supply has been simulated in MATLAB/Simulink and their results are mentioned. 3 sort of loads has been used, One 6-pulse current source converter bridge (Load 1), One 3 phase diode bridge rectifier with an inductance of 300mH (Load 2) and one 3 phase diode bridge rectifier with a capacitance of 1000uF (Load 3). To check the dynamic ability of the novel Shunt Active Power filter, simulation of the unbalanced and distorted supply system has been done once all loads are connected with the system at the completely different time. In this paper, Load one is often connected, Load 2 is at first connected and is disconnected when each 2.5 cycles and load three is connected and disconnected once each half cycle.

A. Simulation results & Discussion of Three-phase balanced supply system

Modeling and simulation for balanced supply condition for 50 Hz supply for all three loads connected together at different time interval have been done. All the simulations have been done for 15 cycles.

a. Simulation results & Discussion of uncompensated system in balanced supply system

Figure 4 presents the waveforms of source current and source voltage. We can see distortions and harmonics added in the source voltage and source current waveforms. After doing simulation in MATLAB/Simulink, it's been discovered that THD of supply current is 25.63% and THD of supply Voltage were 4.1 %. By perceptive these knowledge, we are able to simply perceive that they're out of the limit of IEEE 519-1992 limit. We've got seen that supply has been impure once totally different nonlinear loads are connected.

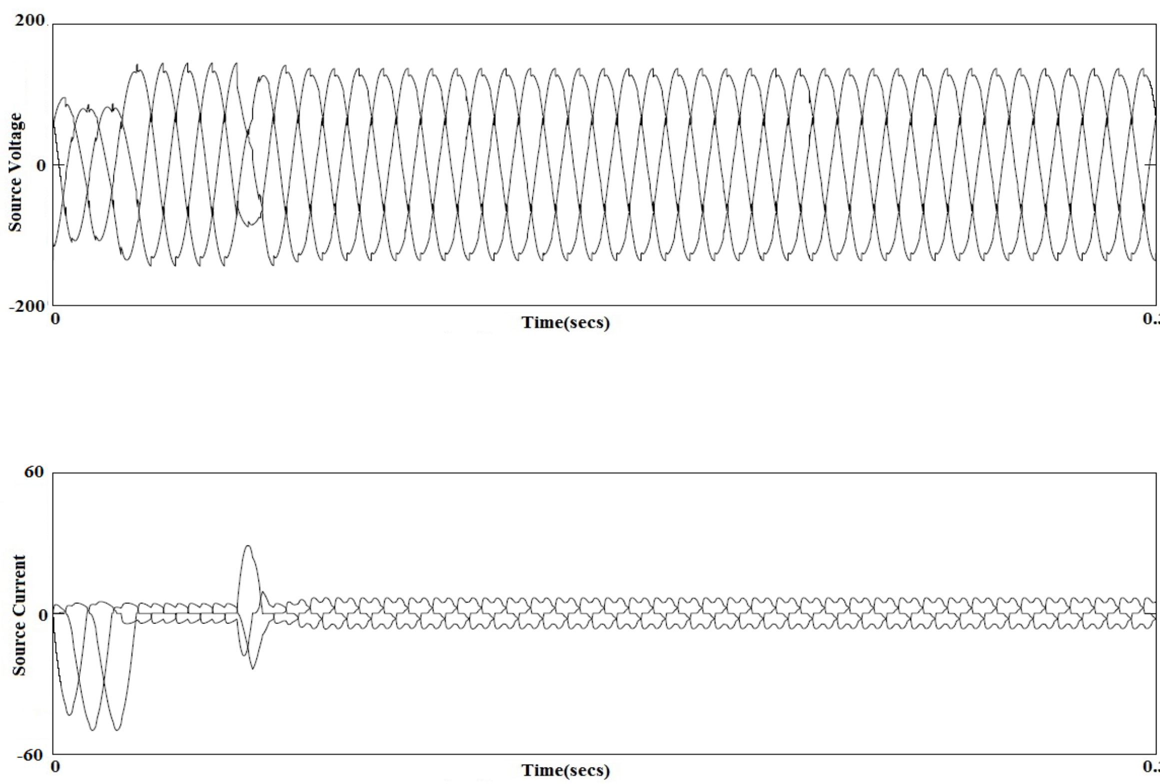

Figure 4. Waveforms of source voltage and source current of all loads connected together at different time interval for balanced supply condition

b. Simulation of Active Power Filter with Sinusoidal Current Control Strategy for Balanced Supply

From the simulation results shown in figure 5, it has been observed that that the THD of source current & source voltage was 1.6% and 3.93% respectively. The compensation time was 0.059 sec. At t=0.059sec, we can see that the waveforms for source voltage and source current have become sinusoidal. From fig. 5, we can see the waveforms of compensation current, dc capacitor voltage and load current. The variation in dc voltage can be clearly seen in the waveforms. As per requirement for increasing the compensation current for fulfilling the load current demand, it releases the energy and thereafter it charges and tries to regain its set value. If we closely observe, we can find out that the compensation current is actually fulfilling the demand of load current and after the active filtering the source current and voltage is forced to be sinusoidal. This can be easily observed that the results are within the limit of IEEE 519-1992 standard defined for voltage and current harmonics.

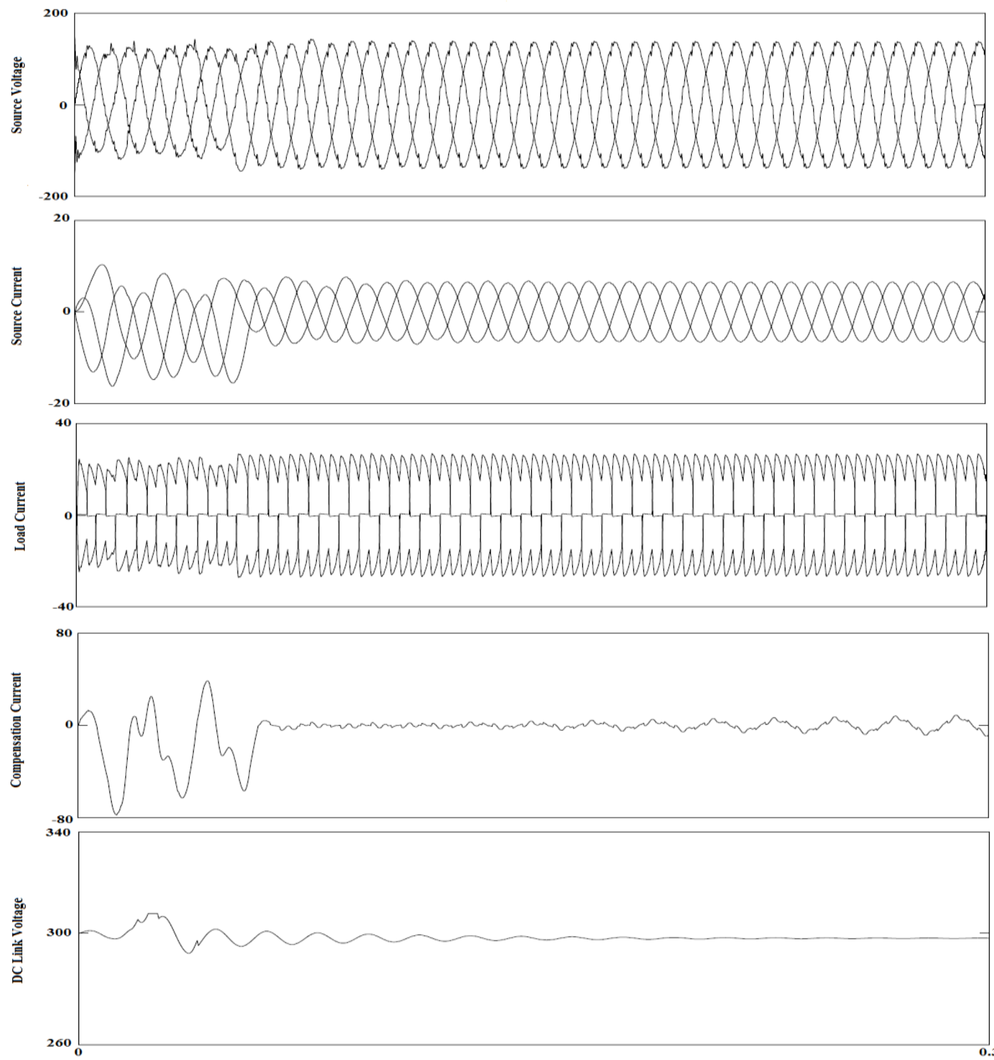

Figure 5. Source Voltage, Source Current, Load Current, Compensation Current (Phase b) and DC Link Voltage Waveforms of Active Power Filter using Sinusoidal Current Control Strategy for all Three Loads Connected Together at Different Time Intervals for Balanced Supply

c. Simulation results & Discussion of Shunt APF using ASNS Algorithm in Balanced Supply System

From the simulation results shown in figure 6, it's been ascertained that the THD of supply current & supply voltage was 1.21% and 2.93% severally. The compensation time was 0.055 sec. At t=0.055 sec, we are able to see that the waveforms for supply voltage and supply current became sinusoidal. From figure 6, we will see the waveforms of compensation current, dc capacitor voltage and load current. The variation in dc voltage is clearly seen within the waveforms. As per demand for increasing the compensation current for fulfilling the load current demand, it releases the energy and thenceforth it charges and tries to regain its set value. If we tend to closely observe, we will conclude that the compensation current is really fulfilling the demand of load current and when the active filtering the supply current and voltage are forced to be sinusoidal.

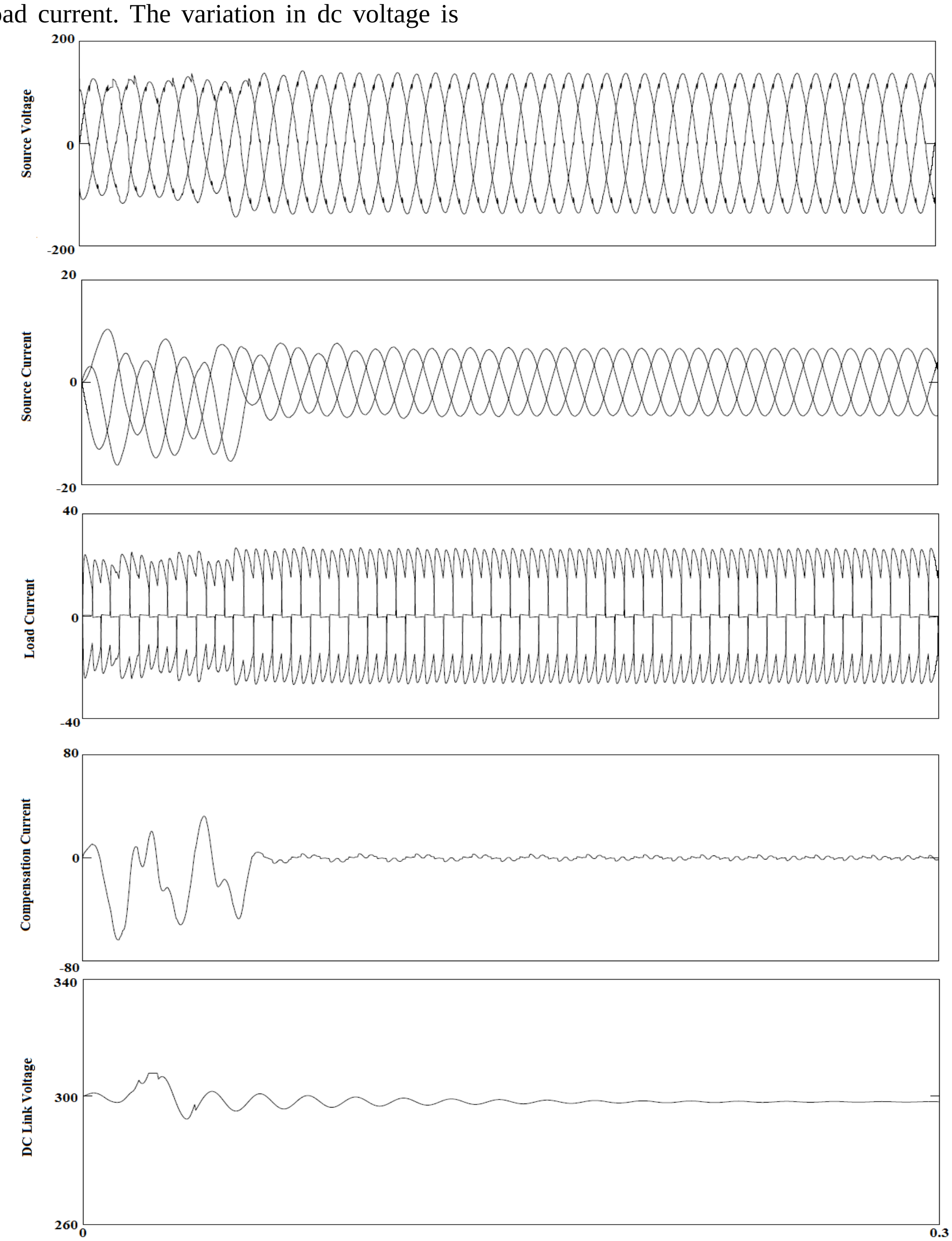

Figure 6 Source Voltage, source current, compensation current (phase b), DC link Voltage and load current waveforms of Active power filter using Sinusoidal Current Control strategy using ASNS Algorithm with all three loads connected together at different time interval for balanced supply system

d. Simulation results & Discussion of Shunt APF using GA in Balanced Supply System

From the simulation results shown in figure 7, it's been ascertained that the THD of supply current & supply voltage was 1.53% and 3.87% severally. The compensation time was 0.057 sec. At t=0.057 sec, we are able to see that the waveforms for supply voltage and supply current became sinusoidal.
From figure 7, we will see the waveforms of compensation current, dc capacitor voltage and load current.

The variation in dc voltage is clearly seen within the waveforms. As per demand for increasing the compensation current for fulfilling the load current demand, it releases the energy and thenceforth it charges and tries to regain its set value. If we tend to closely observe, we will conclude that the compensation current is really fulfilling the demand of load current and when the active filtering the supply current and voltage are forced to be sinusoidal.

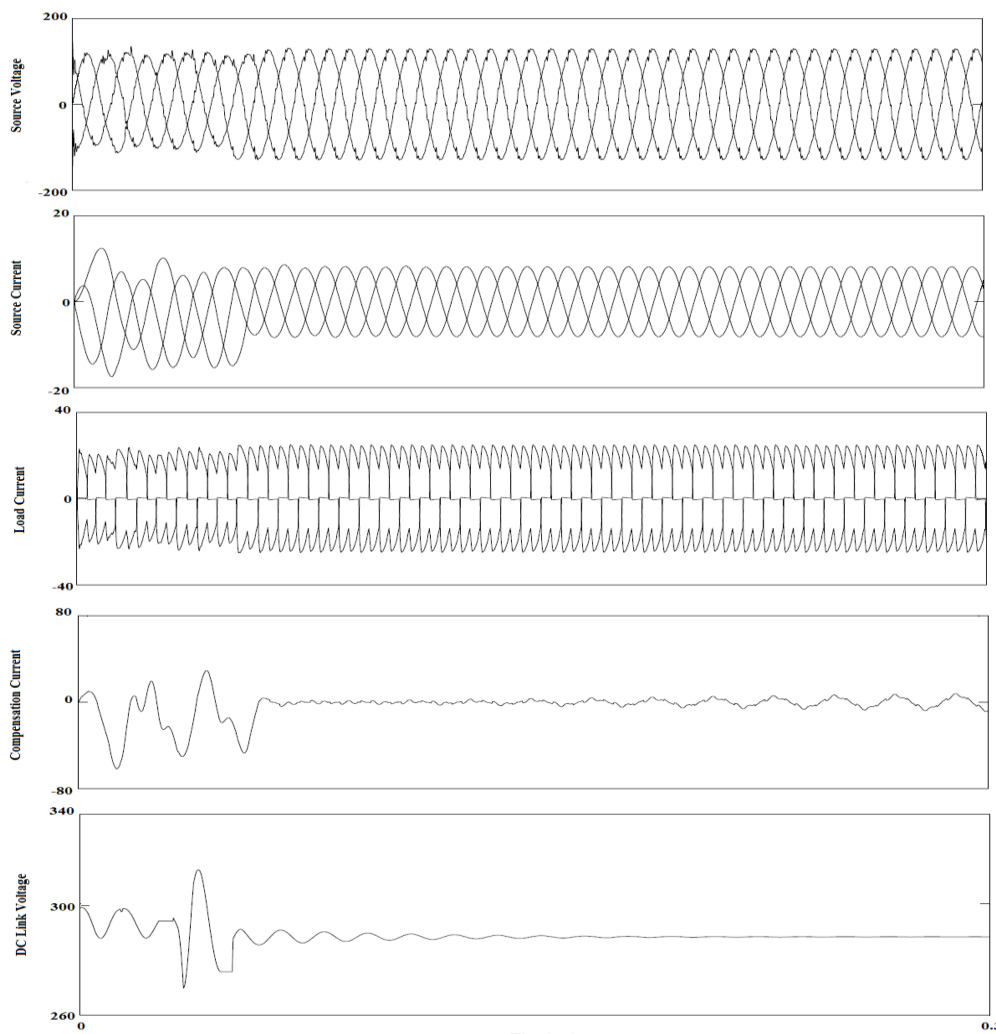

Figure 7 Source Voltage, source current, compensation current (phase b), DC link Voltage and load current waveforms of Active power filter using Sinusoidal Current Control strategy using Genetic Algorithm with all three loads connected together at different time interval for balanced supply system

B. Simulation results & Discussion of three phase unbalanced supply system

In this section, supply system of 110V, 50 Hertz with a step phase variation of 1200 with begin and finish time of 0.01 to 0.15 sec severally i.e.an unbalanced supply system has been simulated.

a. Simulation results & Discussion of uncompensated system in unbalanced supply system

After doing simulation in MATLAB/Simulink while not connecting any filter (Figure 8) i.e. for uncompensated System, it's been ascertained that the THD of supply current found whereas using all 3 loads at the same time connected with the system at completely different time is 26% and THD of supply Voltage were 3.46%. We can see unbalancing, distortions and harmonics added in the source voltage and source current waveforms. By observant these information, we will simply perceive that they're out of the limit of IEEE 519-1992 limit. We've seen that supply has been impure once loads have been connected.

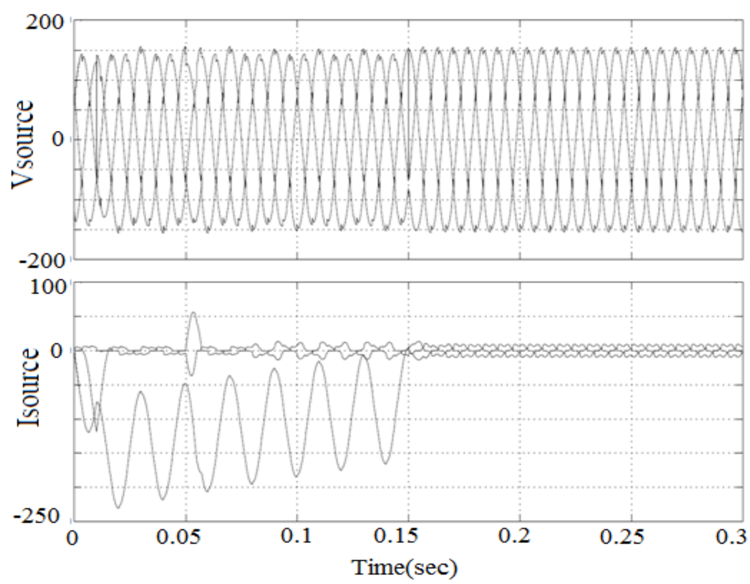

Figure 8. Source Voltage and source current waveforms of uncompensated system for unbalanced supply

b. Simulation of Active Power Filter with Sinusoidal Current Control strategy for Unbalanced Supply

In this section, simulation of Sinusoidal current control strategy of 3 phase balanced supply for different loads has been done. The results of the simulation are shown in figure 9. From the results, it is found that the THDs of source current & source voltage were 1.6% and 4.14% respectively. As we have discussed earlier, unbalanced supply system of 110V, 50 Hz with a step phase variation at 120^0 with start and end time of 0.01 to 0.15 sec respectively has been used. At t=0.17 sec, we will see that the waveforms for supply voltage and supply current became sinusoidal. The compensation time was 0.02 sec. The waveforms of compensation current, dc capacitor, voltage and load current can be seen from figure 9. There is variation in dc voltage which can be seen clearly in the waveforms. If there is need of increasing the compensation current for fulfilling the demand of load current, it releases the energy and after that, it charges and tries to regain its set value.

If we tend to closely observe the waveforms around 0.01 sec and 0.015 sec, it would be understood that the compensation current is truly fulfilling the demand of load current and once the active filtering the supply current and voltage is forced to be sinusoidal.

c. Simulation results & Discussion about the Shunt APF using ASNS algorithm in Unbalanced supply system

From the simulation results shown in figure 10, it's been ascertained that the THD of supply current & supply voltage was 1.14% and 3.44% severally. The compensation time was 0.003 sec. At t=0.153 sec, we are able to see that the waveforms for supply voltage and supply current became sinusoidal.

From figure 10, we can see the waveforms of compensation current, dc capacitor voltage and load current. The variation in dc voltage is clearly seen within the waveforms. As per demand for increasing the compensation current for fulfilling the load current demand, it releases the energy and thenceforth it charges and tries to regain its set value. If we tend to closely observe, we will conclude that the compensation current is really fulfilling the demand of load current and when the active filtering the supply current and voltage are forced to be sinusoidal.

d. Simulation results & Discussion about the Shunt APF using GA in Unbalanced supply system

From the simulation results shown in figure 11, it has been observed that that the THD of source current & source voltage was 1.46% and 3.93% respectively. The compensation time was 0.007 sec. At t=0.157 sec, we can see that the waveforms for source voltage and source current have become sinusoidal.

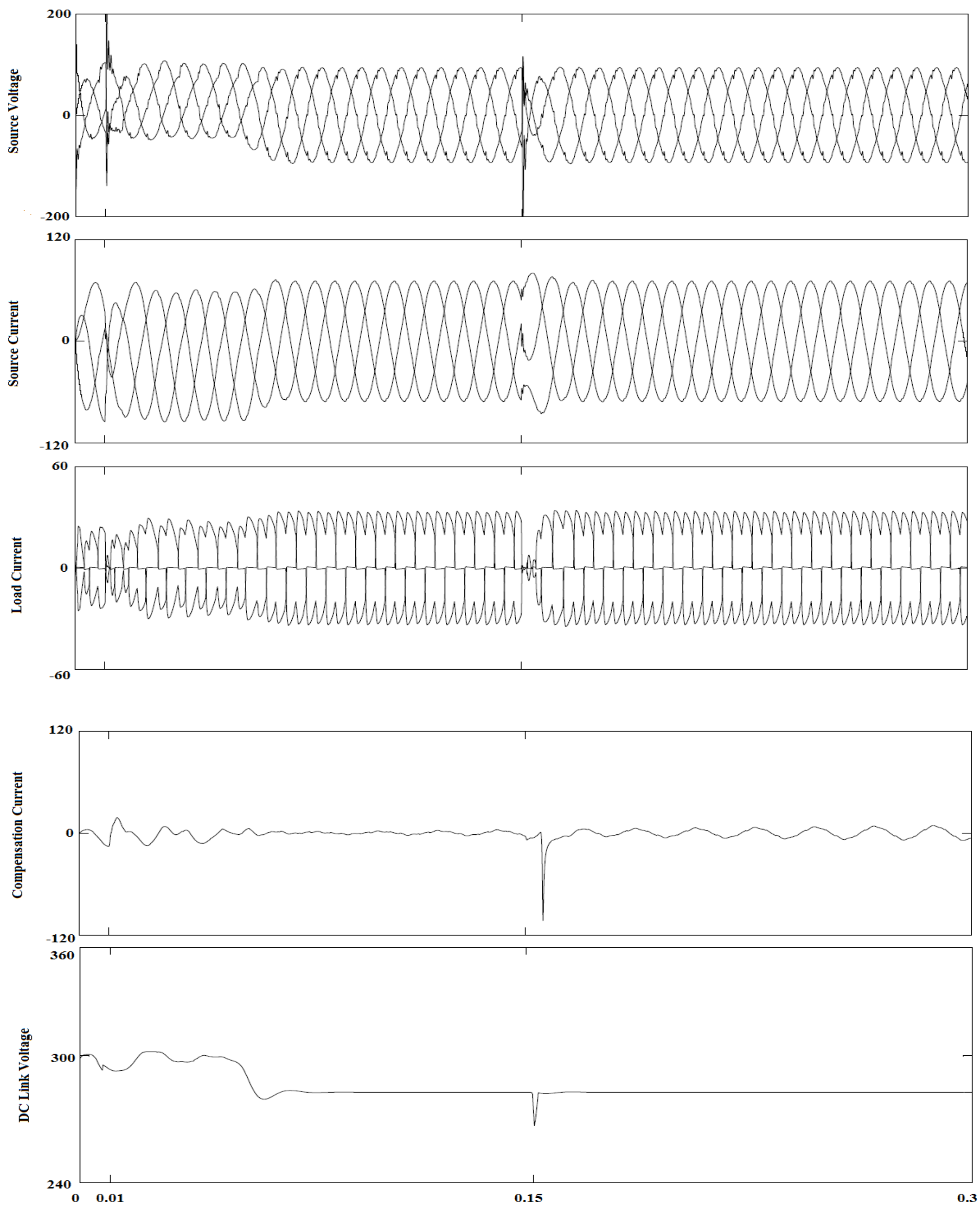

Figure 9. Source Voltage, Source Current, Load Current, Compensation Current (Phase b) and DC Link Voltage Waveforms of Active Power Filter Sinusoidal Current Control Strategy for all Three Loads Connected Together at Different Time Intervals for Unbalanced Supply

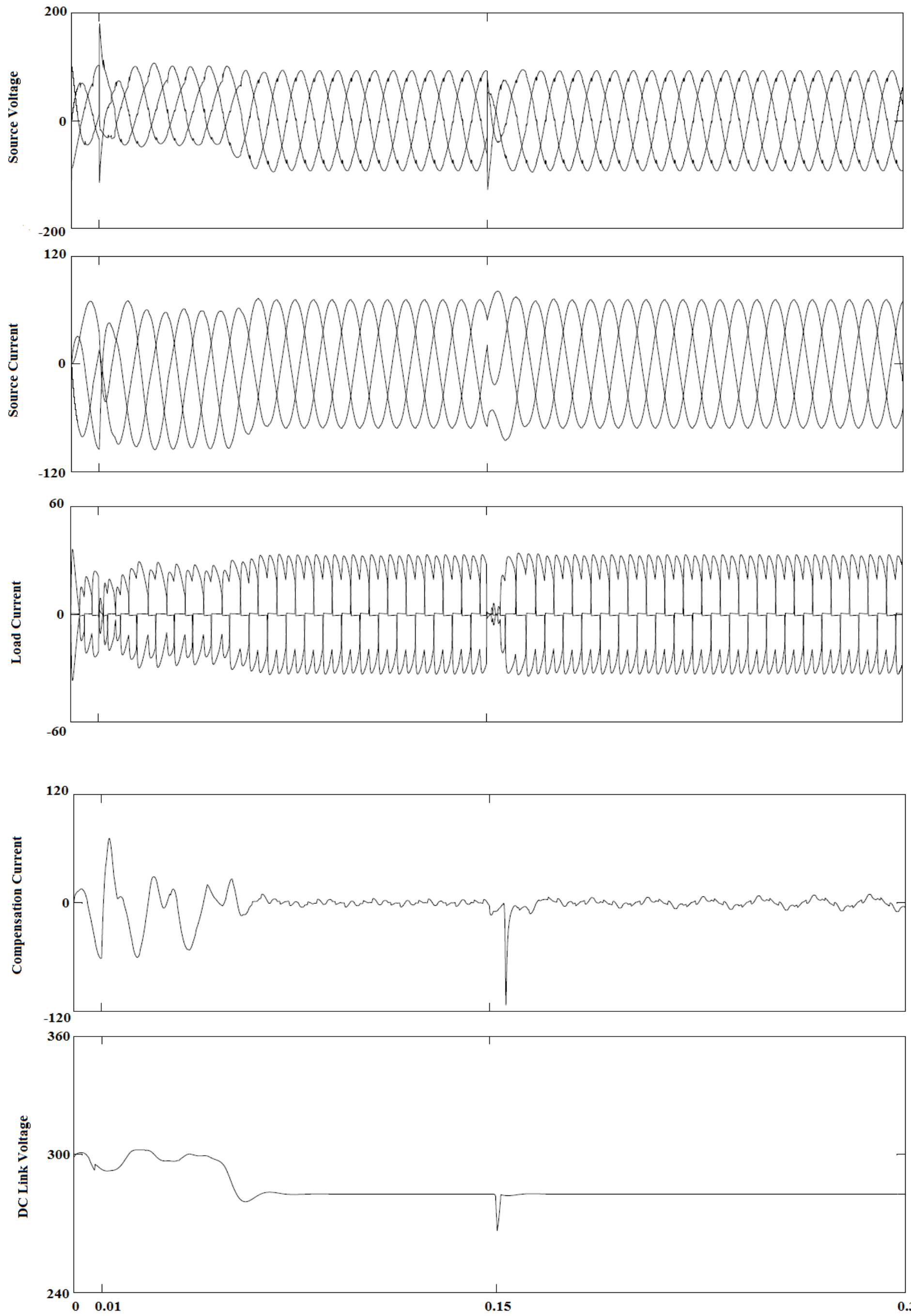

Figure 10. Source Voltage, source current, compensation current (phase b), DC link Voltage and load current waveforms of Active power filter using Sinusoidal Current Control strategy using ASNS Algorithm with all three loads connected together at different time interval for unbalanced supply system

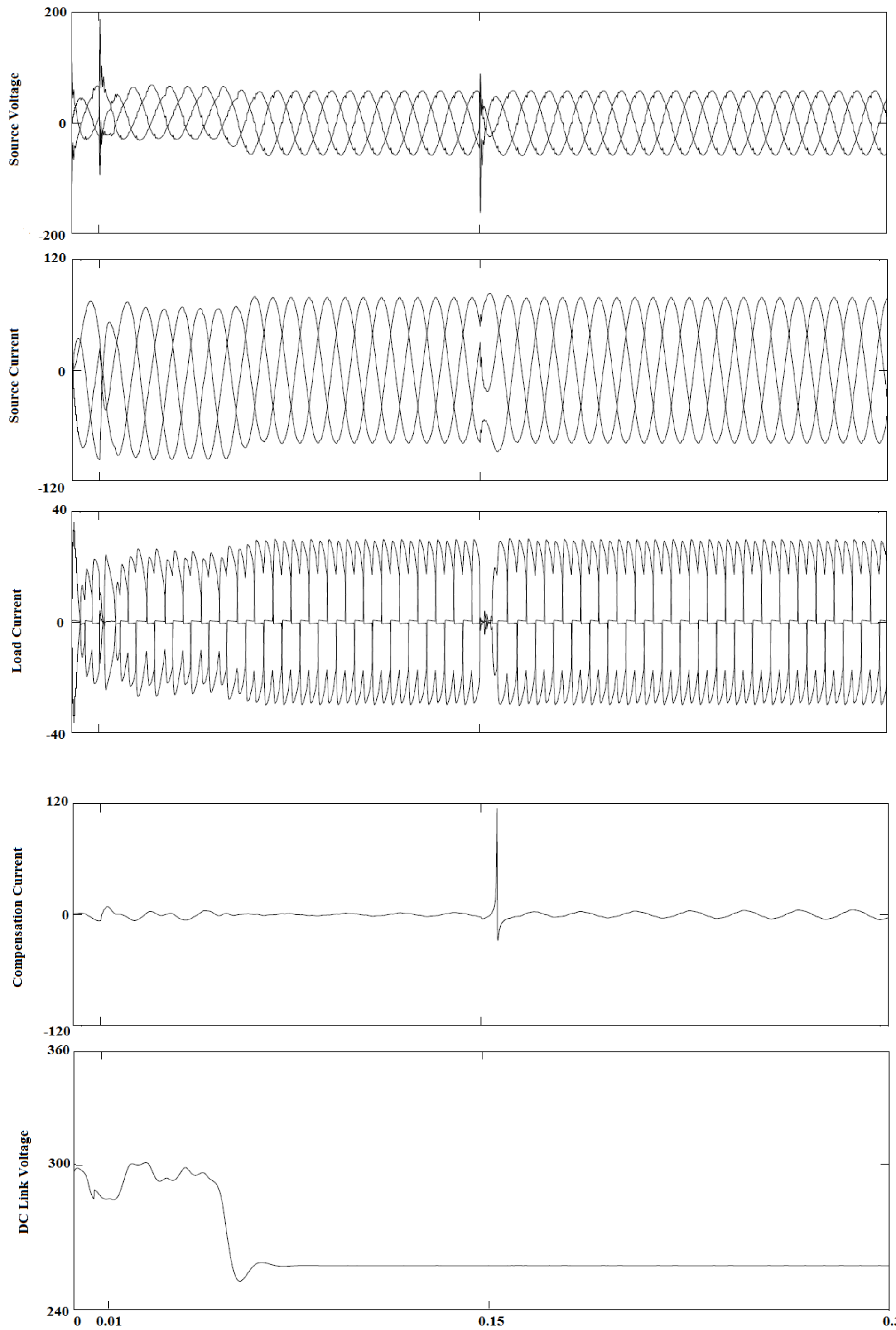

Figure 11. Source Voltage, source current, compensation current (phase b), DC link Voltage and load current waveforms of Active power filter using Sinusoidal Current Control strategy using Genetic Algorithm with all three loads connected together at different time interval for unbalanced supply system

C. Simulation results & Discussion of three phase distorted supply system

In this section, supply system of 110V, 50 Hz with phase A having injection of 3rd order harmonics and phase B having injection of 2nd order harmonics of amplitude 0.2 p.u. at the start time of 0.05, sec and end, time is 0.2 sec has been used.

a. Simulation results & Discussion of uncompensated system in distorted supply system

After doing simulation in MATLAB/Simulink without using any filter (Figure 12) i.e. for Uncompensated System, it has been observed that the THD of source current found while using all three loads simultaneously connected with the system at a different time is 26% and THD of source Voltage were 3.46%. By observing these data, we can easily understand that they are out of the limit of IEEE 519-1992 limit. We have seen that supply has been polluted when loads have been connected.

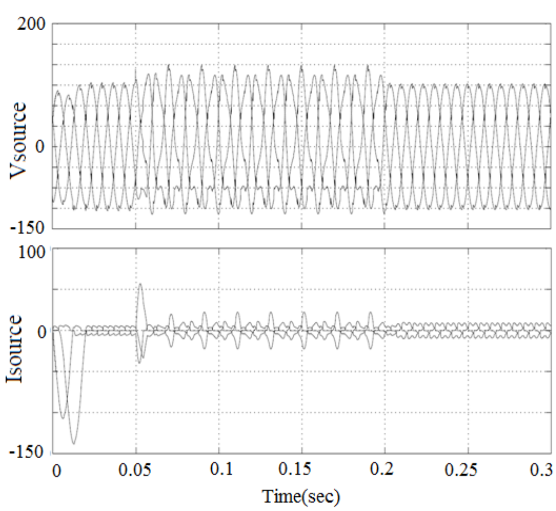

Figure 12. Source Voltage and Source Current Waveforms of Uncompensated System for Distorted Supply

b. Simulation of Sinusoidal Current Control Strategy for 3 Phase Distorted Supply

In this section, simulation of Sinusoidal current control strategy of 3 phase distorted supply for different loads has been done. From the simulation results shown in figure 13, it's been ascertained that that the THD of supply current & supply voltage was 1.6% and 4.14% respectively. As we have discussed earlier, distorted supply system of 110V, 50 Hz with phase A having injection of 3rd order harmonics and phase B having an injection of 2nd order harmonics of amplitude 0.2 p.u. at the start time of 0.05 sec and end, time is 0.2 sec has been analyzed. At t=0.22 sec, we will see that the waveforms for supply voltage and supply current became sinusoidal. The compensation time was 0.02 sec. From figure 13, we will see the waveforms of compensation current, dc capacitance voltage, and load current. The variation in dc voltage will be clearly seen within the waveforms. As per demand for increasing the compensation current for fulfilling the load current demand, it releases the energy and thenceforth it charges and tries to regain its set value. If we have a tendency to closely observe the waveforms around 0.05 sec and 0.2 sec, we are able to conclude that the compensation current is really fulfilling the demand of load current and when the active filtering the supply current and voltage are forced to be sinusoidal.

c. Simulation results & Discussion about the Shunt APF using ASNS algorithm in Distorted supply system

From the simulation results shown in figure 14, it's been ascertained that the THD of supply current & supply voltage was 1.11% and 3.48% severally. The compensation time was 0.001 sec. At t=0.0201 sec, we are able to see that the waveforms for supply voltage and supply current became sinusoidal.

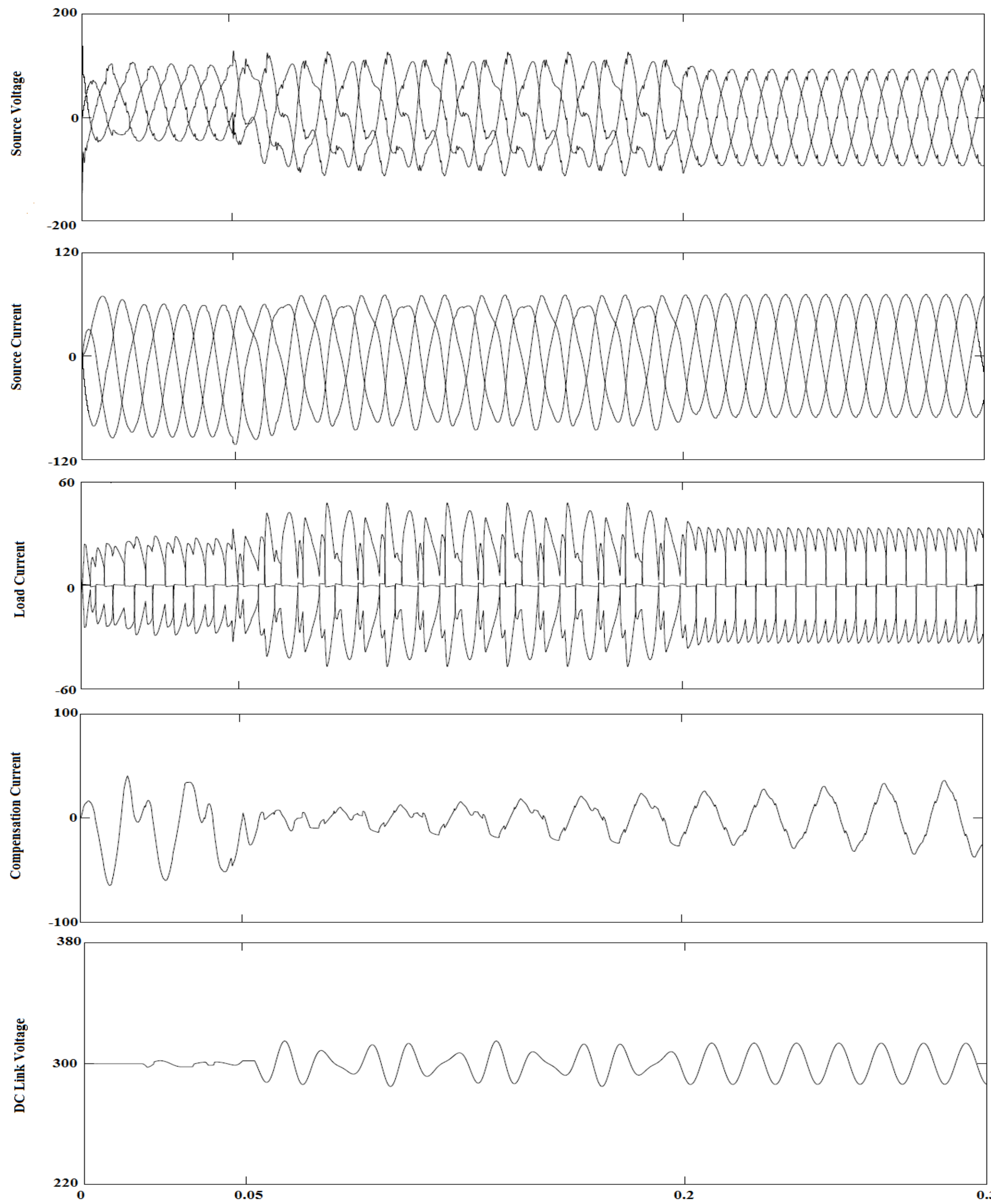

Figure 13. Source Voltage, Source Current, Load Current, Compensation Current (Phase b) and DC Link Voltage Waveforms of Active Power Filter Sinusoidal Current Control Strategy for all Three Loads Connected Together at Different Time Interval for Distorted Supply

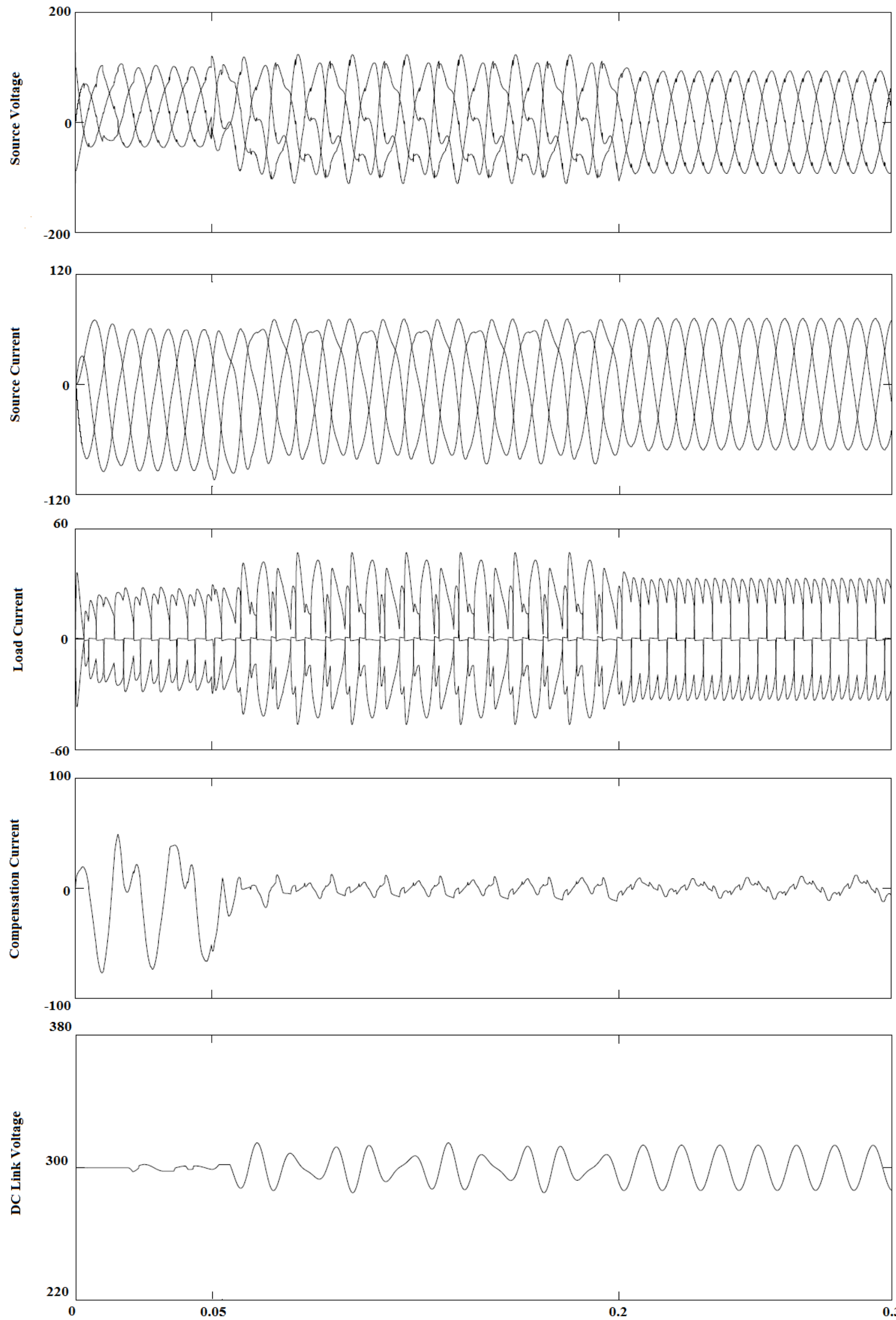

Figure 14. Source Voltage, source current, compensation current (phase b), DC link Voltage and load current waveforms of Active power filter using Sinusoidal Current Control strategy using ASNS Algorithm with all three loads connected together at different time interval for distorted supply system

d. Simulation results & Discussion about the Shunt APF using GA in Distorted supply system

From the simulation results shown in figure 15, it's been ascertained that the THD of supply current & supply voltage was 1.46% and 3.94% severally. The compensation time was 0.002 sec. At t=0.202 sec, we are able to see that the waveforms for supply voltage and supply current became sinusoidal.

The simulation waveforms shown above and also the result tabulated in table 1 and table 2 confirms that the novel ASNS algorithm primarily based Shunt APF can perform well in balanced, unbalanced and distorted supply system and it dynamic ability and superiority over typical sinusoidal current control technique and its optimized version using GA technique by perceptive its least THD and less compensation time.

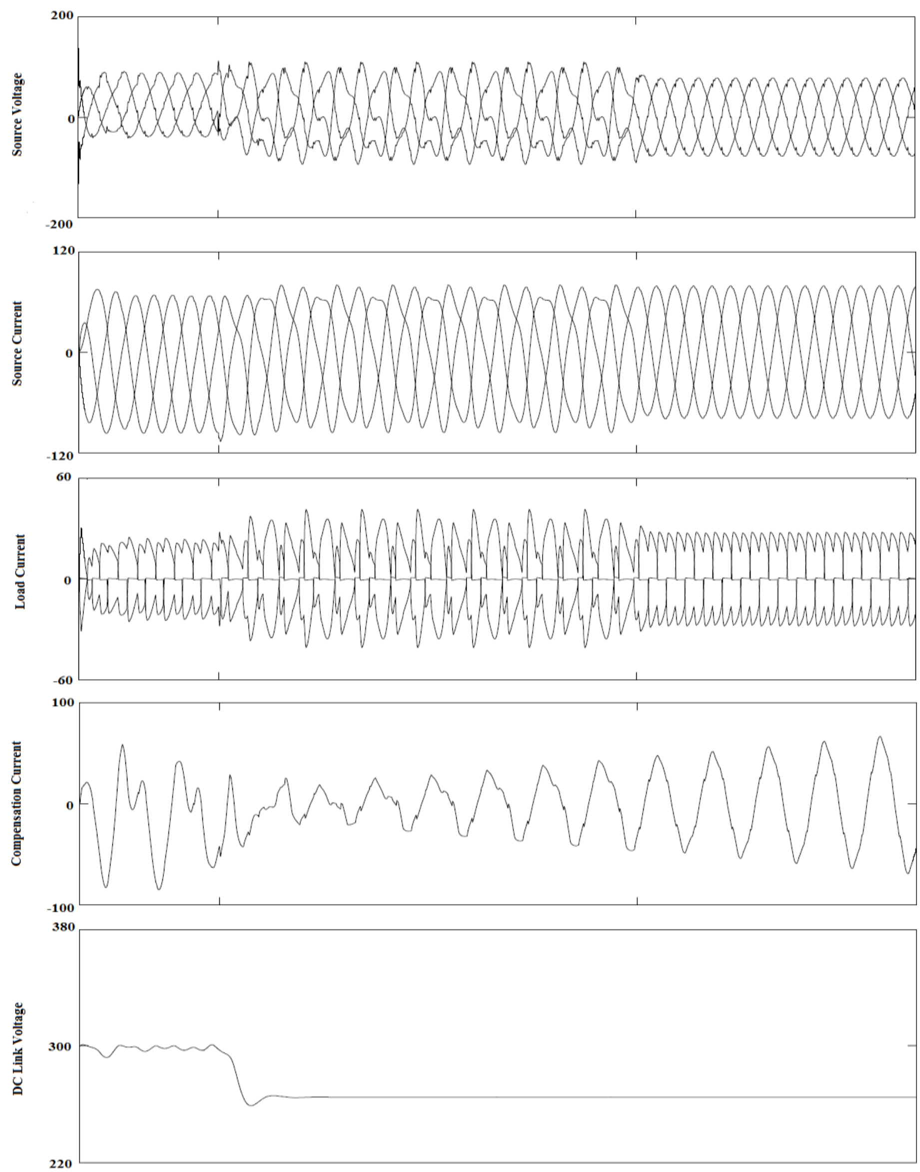

Figure 15. Source Voltage, source current, compensation current (phase b), DC link Voltage and load current waveforms of Active power filter using Sinusoidal Current Control strategy using Genetic Algorithm with all three loads connected together at different time interval for distorted supply system

We are able to observe clearly that ASNS is best yet as quickest in all 3 supply conditions, that proves its superiority over GA and traditional control technique.

TABLE I THD OF UNCOMPENSATED SYSTEM

System details	THD-I (%)	THD-V (%)
Balanced Supply	25.63	4.1
Unbalanced Supply	26	3.46
Distorted Supply	26	3.46

TABLE II THD & COMPENSATION TIME OF COMPENSATED SYSTEM

Supply System	Control Technique Used	THD-I (%)	THD-V (%)	Compensation Time(sec)
Balanced	Conventional	1.6	3.93	0.059
Balanced	ASNS	1.21	2.93	0.055
Balanced	GA	1.53	3.87	0.057
Unbalanced	Conventional	1.6	4.14	0.020
Unbalanced	ASNS	1.14	3.44	0.003
Unbalanced	GA	1.46	3.93	0.007
Distorted	Conventional	1.72	3.96	0.016
Distorted	ASNS	1.11	3.48	0.001
Distorted	GA	1.46	3.94	0.002

5. CONCLUSION

A novel improved algorithm i.e. Adaptive Spider Net Search (ASNS) algorithm applied in shunt active power filter has been presented, which works effectively under the balanced, unbalanced & distorted supply conditions. System optimization by using Adaptive Spider Net Search algorithm has well worked for the model using conventional Sinusoidal Current control Technique. ASNS has effectively compensated the system. THD for source current and source voltage has been reduced significantly over a very little time of few seconds. While comparing with the conventional as well as advanced GA technique, it can be clearly said that ASNS is better as well as faster than both techniques. The simulation results clearly prove ASNS Algorithm superiority over GA and conventional control technique.

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Saifullah Khalid born in Varanasi, Uttar Pradesh, INDIA. He has completed bachelor of Engineering from North Maharashtra University, Jalgaon, MS, India, M.Tech degree from MMMEC Gorakhpur. India and Ph.D. from Institute of Engineering & Technology, Lucknow, UP, India. He is presently working as Manager (ATC) \at Lucknow Airport. His area of interest is development and application of novel optimization algorithms in active power filter. He is the author of more than 90 papers and 07 books.